GARRAD HASSAN

ASSESSMENT OF ICE THROW RISK FOR THE PROPOSED EAST HAVEN WIND FARM

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1 INTRODUCTION

1.1 Scope and objective

Garrad Hassan America, Inc. (GH) has been contracted by East Haven Wind Farm (EHWF) to undertake an assessment of the risk of ice fragments shed from wind turbines striking people in the vicinity of the proposed East Haven Wind Farm in Vermont.

The assessment reported here has been performed in accordance with the proposal provided to EHWF [1] and its objective was to quantify the risk of ice striking people utilizing the neighbouring land of the proposed wind farm and to recommend a control strategy to prevent this risk. This report presents the findings of the work undertaken by GH.

1.2 Assessment subject

The East Haven Wind Farm site is located approximately 9 km (5.5 miles) east of the village of East Haven in northeastern Vermont along a northwest to southeast ridge with an elevation of approximately 1025 m (3360 ft) above sea level. The project proposed by EHWF would use four General Electric Wind Energy (GEWE) 1.5s wind turbines each with a rated capacity of 1.5 MW. The proposed layout of the wind turbines is represented in Figure 1 and some key parameters of the wind turbines are summarised in Table 1.

Wind turbine model	**GEWE 1.5s – 1.5 MW**
Rotor diameter	70.5 m (231 ft)
Hub height	65 m (213 ft)
Nominal rotor speed	11.1 – 22.2 rpm
Nominal tip speed	41 – 82 m/s (92 – 183 mph)

Table 1 Wind turbine parameters

The neighbouring property, which is the subject of this assessment, is defined as the land outside of the site boundary of the proposed wind farm as shown in Figure 1. Turbines will be positioned so that there is no overhang of the blades on surrounding property, with the base of the towers up to 60 m (200 ft) from the boundary.

1.3 Wind turbine icing

Ice can build up on wind turbine rotor blades, as it does on any structure which is exposed to the elements, when appropriate conditions of temperature and humidity exist. When a wind turbine is stationary, it is no more likely to suffer from ice accretion than a large stationary structure such as a building, tree or power line. Like such structures, accreted ice will eventually be released and fall directly to the ground.

However, when operating, which will typically be when the wind speeds at the wind turbine hub height are in the range 4 m/s to 25 m/s (9 mph to 56 mph), ice can accrete on the rotor blades. In this case, observations suggest that higher ice accretion rates occur due to the relative velocity of the rotor blades. Additionally, ice fragments which detach from the rotor blades can be thrown significant distances from the wind turbine. Any fragments will land directly below the wind turbine, in the plane of the wind turbine rotor or downwind.

In situations when a risk is perceived due to icing of rotor blades, it is common for mitigation measures to be taken in terms of automated or manual by remote operation shutdown of the wind turbines. It is noted that remote monitoring and operation of wind farms is now standard in the industry.

2 ASSESSMENT METHODOLOGY

The assessment methodology used here is based on that developed by GH in conjunction with the Finnish Meteorological Institute and Deutsches Windenergie-Institut as part of a research project on the implementation of wind energy in cold climates (WECO) primarily funded by the European Union and also supported in part by the United Kingdom Department of Trade and Industry [2]. The guidelines for safety assessments in relation to ice throw were developed by GH in the WECO project and that work was summarized in a series of conference papers [3,4,5]. These guidelines have been applied to the EHWF site by considering the proposed turbine type, the terrain of the site and surrounding area, and assumptions for human presence in the surrounding area.

The overall approach is presented schematically in Figure 2 and is based on a staged approach:

- Determining the periods when ice accretion on structures is technically possible, based on historical climatic observations.
- Within those periods, determining when the wind speed conditions are within the operational range of the wind turbines.
- Within the resultant periods, excluding those periods when the wind turbines will be shut down automatically by the wind turbine control system or by remote operators.
- Based on an estimate from the above of the amount of icing, use guidelines (Figure 4) to arrive at probability of fragments landing at distances from the turbines up to a conservative estimate of the theoretical maximum distance of ice throw, considering the slope of the terrain and parameters of the considered wind turbines.
- Estimate probability of people being present within the distances from the turbine which are being considered.
- Arrive at combined probability of people being hit by ice fragments.
- Compare that probability to a suitable benchmark risk – the most commonly used one being the risk of being struck by lightning.

3 DATA SOURCES AND OTHER INPUTS

3.1 Burke Mountain

The closest suitable source of available reference data is at Burke Mountain which is located approximately 15 km (9 miles) to the southwest of the East Haven site at an elevation of 990 m (3250 ft) above sea level.

Climatic data recorded at Burke Mountain for the period between February 1999 and December 2004 have been analysed. The data sets available were:

- Average wind speed from both heated and unheated instruments
- Average wind direction from both heated and unheated instruments
- Air temperature

3.2 Data from site

Data from two meteorological towers on site have been made available with wind data and air temperature between January 2002 and January 2005. Data from this mast have been collated and analysed by the consultancy AWS Scientific [6].

3.3 Assessment guidelines and data

The guidelines produced in the WECO project were based on a combination of numerical modelling and observations.

The numerical modelling involved Monte-Carlo simulations of a range of scenarios of ice building up on a wind turbine and being shed from the rotor blades. This was based on a wind turbine of 50 m (164 ft) rotor diameter and 40 m (131 ft) hub height. However, parametric studies indicated that compared to the tip speed, which was 65 m/s (15 mph) for the simulations, other wind turbine parameter were relatively unimportant. The literature also identifies the sensitivity of the results to tip speed, indicating a general increase of 15% for the GE1.5s, assuming the worst case of continuous operation at its peak speed. The results of the simulations are therefore considered to remain valid for application in the case of the GE1.5s model.

In the modelling, further assumptions were required in regard to the aerodynamic properties of ice fragments. These assumptions were verified during the course of the WECO project by measuring the lift and drag characteristics of models of typical ice fragments in wind tunnels. Those coherent fragments collected from various icing events were irregular blocks shed from the leading edge of the rotor blades. Moulds were produced from these and replicas cast for wind tunnel testing. No stable lifting situation was measured leading to a conclusion that the lift coefficient could be neglected. The drag coefficient meanwhile was measured to fall in the same range as was assumed in the modeling described above.

In the EU study, the observations of ice build-up on rotor blades and fragments shed from rotor blades were gathered from wind farms throughout Europe. The data gathered are presented in Figure 3, which shows that fragments typically land within 100 m (328 ft) of the wind turbine. Ice fragments with masses up to 1 kg were found, although most were much smaller.

As a result of the work, the chart of Figure 4 was proposed for use in risk assessment where detailed assessment was required.

4 CONTROL METHODOLOGIES

No specific control strategies for icing conditions have been proposed by EHWF. A suggested control methodology is described here.

It is recommended that an ice detector be mounted to the nacelle of Wind Turbine No. 2. The signal from the ice detector is to be monitored by the turbine control system, triggering shutdown of all four turbines when the icing is detected.

It is understood from EHWF that there is no weather chart or ice rain forecast available for the East Haven area. In the absence of this information and as backup for the automated system, it is recommended that suitable data be recorded on site, including a remote and heated video feed, to determine icing conditions and that a remote operator be instructed to shut the system down when such conditions are detected.

In either of these events, all four turbines are to be placed in Pause mode, in which the units are inoperative and it should be possible to stop the turbine at a specific yaw orientation and rotor azimuth position to maximize the distance of the turbine blades to the site boundary. A visual inspection of the turbines either by remote video feed or onsite should be required prior to re-start.

5 RESULTS OF ASSESSMENT

5.1 Technical feasibility of icing

AWS Scientific has reported [6] that a loss of up to 8% on the estimated annual energy production can be expected for icing conditions at the proposed EHWF site. This value is roughly equivalent to 15 to 25 days in the year that are affected by icing events.

In the attempt to confirm this prediction, the Burke Mountain measurements have been used as a primary source of data as they offer a relatively consistent long-term data set, in a very similar climate and exposure to that at the East Haven Wind Farm.

Given the close proximity and the similar elevation of Burke Mountain to the East Haven Wind Farm site, the Burke Mountain measurements are deemed to be representative of the wind farm site conditions without any necessary adjustments.

The analysis of the Burke Mountain measurements has focused on the visual inspection of concurrent time series plots where wind measurement sensors were frozen and, when available, the recorded temperature was between +1 and -5 degrees Celsius.

The result of this analysis is that between 35 and 75 days in the year may be affected by icing events. There are important issues and factors which it has not been possible to resolve or consider which may cause extreme conservatism in the above value:

- The quality of the wind and temperature data recorded at Burke Mountain is considered to be very poor with a considerable amount of apparent equipment malfunction or calibration. Most notably is that the recorded temperatures prior to November 2002 and between January and March 2003 are erroneous. Consequently, GH had to make the conservative assumption that for the Burke Mountain data between September and May of a given year, all frozen signals with no concurrent temperature were assumed to be the result of icing.

- No suitable information is available on humidity from Burke Mountain. Therefore, GH assumed that suitable humidity conditions for ice formation always exist at the site when frozen signals were encountered or when near zero temperature were recorded.

- The analysis has used ten-minute data and assumed that every ten-minute period when suitable conditions exist will result in an iced rotor and ice throw, when in fact a single ten-minute period may not be adequate time for ice to form. Against that, ice formed on blades may persist for some time after the suitable conditions desist.

It is also noted that anecdotal evidence consisting of an interview with AWS Scientific and operational wind farm reports from the Green Mountain Power Wind Farm in southern Vermont [7,8] have indicated that the icing can be expected between 1 to 25 days during the year. These sources have also suggested that typical icing events would yield glaze ice thicknesses between 0.25 and 1 inches with rare extreme events having ice thickness up to 2 inches.

Given the value reported by AWS, the anecdotal evidente collected and the uncertainties in the Burke Mountain measurements, it is considered that a value of 25 days of icing a year is representative of the EHWF site and has been used for the purpose of this risk assessment.

5.2 Human presence and risk

The probability of the general public straying onto the EHWF land marked in Figure 1 is assumed to be nil given adequate fencing of the EHWF property, the gate on the access road, and the posting of signs along the property lines. There is no information available on the likelihood of the general public being in the immediate area surrounding the EHWF land.

This lack of information limits substantive analysis along the lines proposed in the WECO project although there is the obvious conclusion that the general public are not at risk inside the EHWF lands. However based on our previous work [3] and accounting for the terrain and machine size of the EHWF site, a very conservative estimate for the maximum achievable distance for ice to be thrown is considered to be 400 m (1315 ft). Assuming an area within the maximum achievable distance from the proposed EHWF turbines is populated by one ever-present person during all icing conditions and that person is equally likely to be in any given 1 m^2 within that area, it is possible to estimate the risk for one person from ice throw. This risk assuming no-one impinges within 40 m (130 ft) of a turbine base, and assuming that no control method is employed to prevent ice throw is 1 in 11,000,000.

It is noted that a relatively large number of people, roughly 15, must be present before the risk becomes comparable to natural events such as being struck by lightning with an approximate odd of 1 in 750,000 in the United States [9]. Given the dense forest cover of the area surrounding the EHWF land, it can also be expected that the risk could be significantly less as ice fragments could potential hit trees resulting in addition protection.

5.3 Control mitigation

The level of risk presented above is clearly very low. However, the assessment that led to these estimates has required several assumptions and it would therefore be prudent that a control method be employed to eliminate the risk of potentially-damaging ice fragments.

The automatic and remote operation shutdown strategies suggested in Section 4 should be sufficient to identify periods when icing is likely and to shut down all turbines in response. The ice sensor can also be expected to give a direct early measurement of ice starting to build up as well as the point at which icing conditions cease. It is important that all associated equipment for this system be diligently installed and maintained and that the control algorithm be satisfactorily implemented so that all four turbines will shut down in the event of ice starting to build up and re-start only once such conditions cease.

If the ice sensor and the relevant turbine system is diligently implemented and maintained, the suggested remote operator intervention is expected to simply serve as a fall-back.

With these control systems in place, one can expect the ice build-up on the turbines to be no more than on any large stationary structure with no risk of ice fragments being thrown from an operating rotor.

As with a large stationary structure, the risk remains of ice forming at a slow rate on the structure and dropping from the stationary turbine. By comparison to an operating turbine only a small amount of ice is likely to form. As this thaws, there will be some wind blow effect although that will be small on all but the lightest particles. GH estimates that only very high winds may cause fragments of any significant mass to be blown beyond the EHWF boundary.

However, the proximity of the wind turbines to the EHWF boundary means that it may be prudent to refine the shutdown strategy so that the turbine rotors are positioned to maximise clearance of the turbine blades to the site boundary. Furthermore, some warning signs posted along the property lines may be appropriate as an additional safeguard.

6 CONCLUSIONS

Garrad Hassan America, Inc. (GH) has been contracted by East Haven Wind Farm (EHWF) to undertake an assessment of the risk of ice fragments shed from wind turbines striking people in the vicinity of the proposed East Haven Wind Farm in Vermont. The conclusions of the work undertaken are as follows:

- The risk to the public due to any ice fragments shed by the wind turbines comes from an estimation of the probability that ice will land in an area combined with the probability that a member of the public would at that time be present.

- The probability of public access to the EHWF lands has been assumed to be zero and that immediately around the boundaries of the EHWF lands has been estimated, based on an area defined by a conservative estimate of the maximum achievable distance that ice can be thrown, and assuming one person is ever-present during all icing conditions.

- The number of days per year when icing conditions persist is uncertain falling in the range of a few days per year to a few tens of days depending on the source of information. Given the available meteorological data and anecdotal evidence collected, a value of 25 days per year has been assumed to be appropriate to characterize icing conditions at the EHWF site.

- If an effective ice detection and shutdown system such as outlined herein is correctly operated, the probability of ice fragments falling outside the EHWF lands can be neglected.

- In the absence of such a protection system, the overall probability of a member of the public being hit by ice is estimated to be 1 in 11,000,000 given that one person is ever-present during all icing conditions.

REFERENCES

1. M P LeBlanc, "Assessment of ice throw risk for the proposed East Haven Wind Farm", Garrad Hassan America Inc, Proposal Document No. 9606/AP/01 ISSUE B, 1 December 2004.

2. C Morgan et al, "Wind energy production in cold climate (WECO)", ETSU contractor's report W/11/00452/REP, UK DTI, 1999.

3. C Morgan and E Bossanyi, "Wind turbine icing and public safety - a quantifiable risk?", Proceedings of Boreas III conference, Sariselka, Finland 1996.

4. E Bossanyi and C Morgan, "Wind turbine icing – its implications for public safety", Proceedings of European Union Wind Energy Conference 1996.

5. C Morgan, E Bossanyi and H Seifert, "Assessment of safety risks arising from wind turbine icing", Proceedings of EWEC '97 conference, Dublin 1997.

6. AWS Scientific, Inc., "Estimation of the Long-Term Wind Speed and Energy Production at the Proposed East Mountain Wind Project Site", EHWF-MR-4, 1 October 2003.

7. "Green Mountain Power Wind Power Project Second Year Operating Experience: 1998-1999", EPRI TR-113917, December 1999.

8. "Green Mountain Power Wind Power Project Third Year Operating Experience: 1999-2000", EPRI 1000960, December 2000.

9. H Blatt, "Our Geologic Environment", Prentice Hall, 1997, p. 35.

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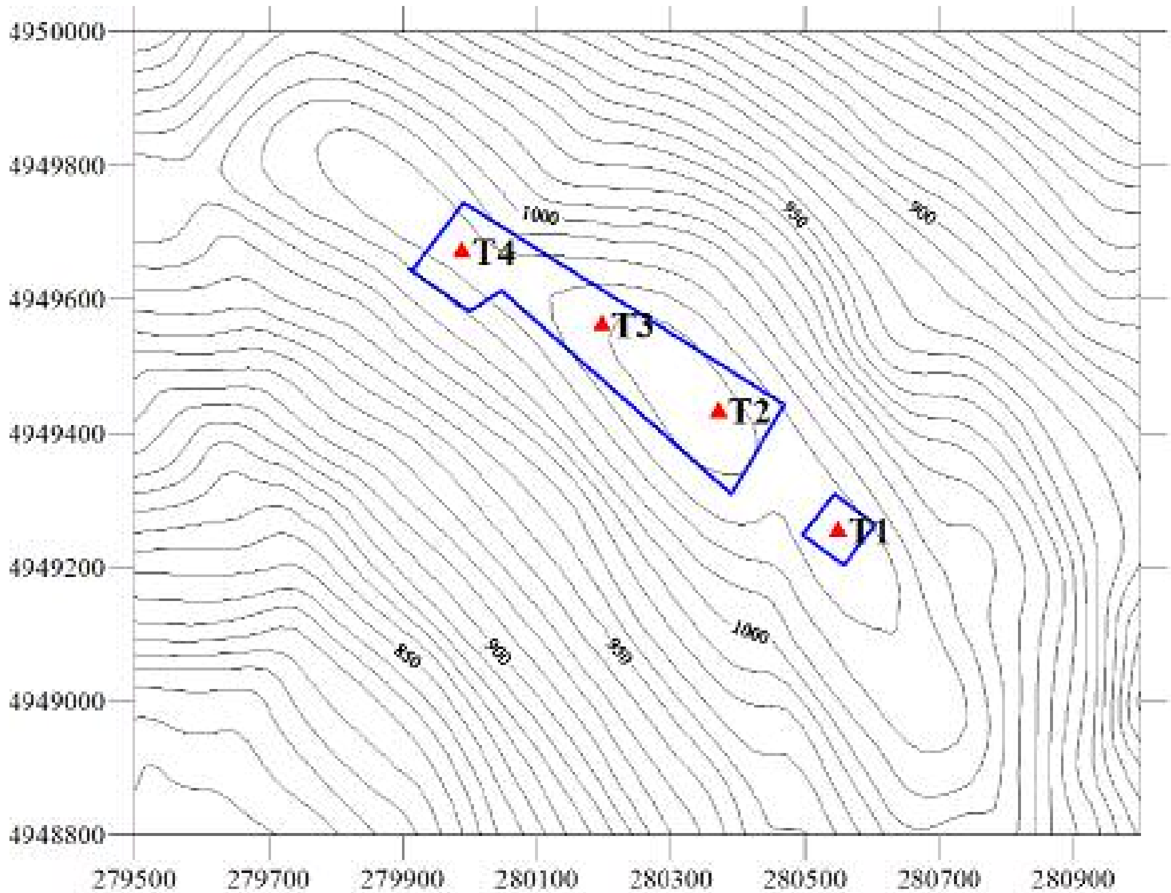

Figure 1 Terrain 10 m contours, proposed turbine locations, and property boundary

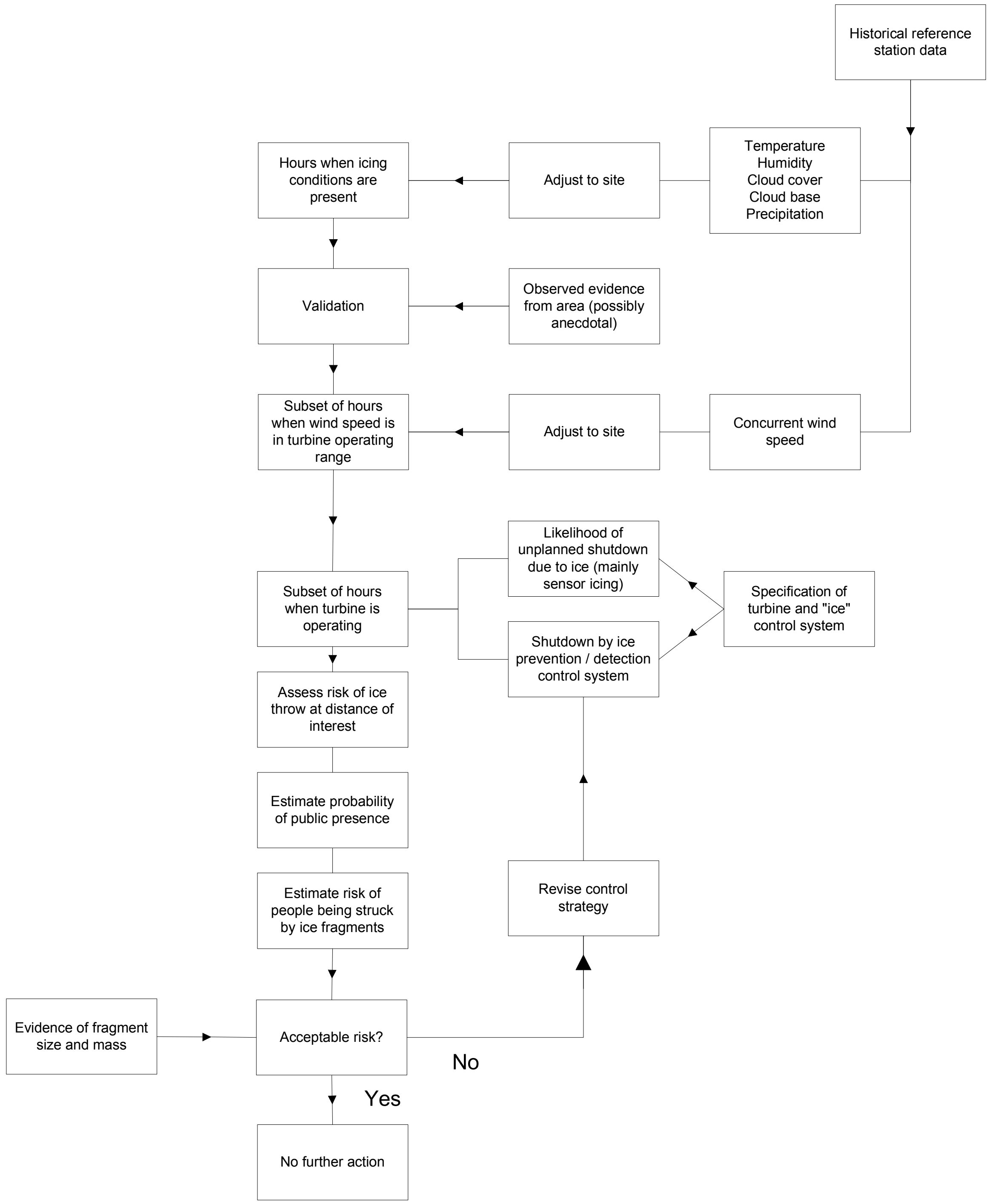

Figure 2 Assessment procedure

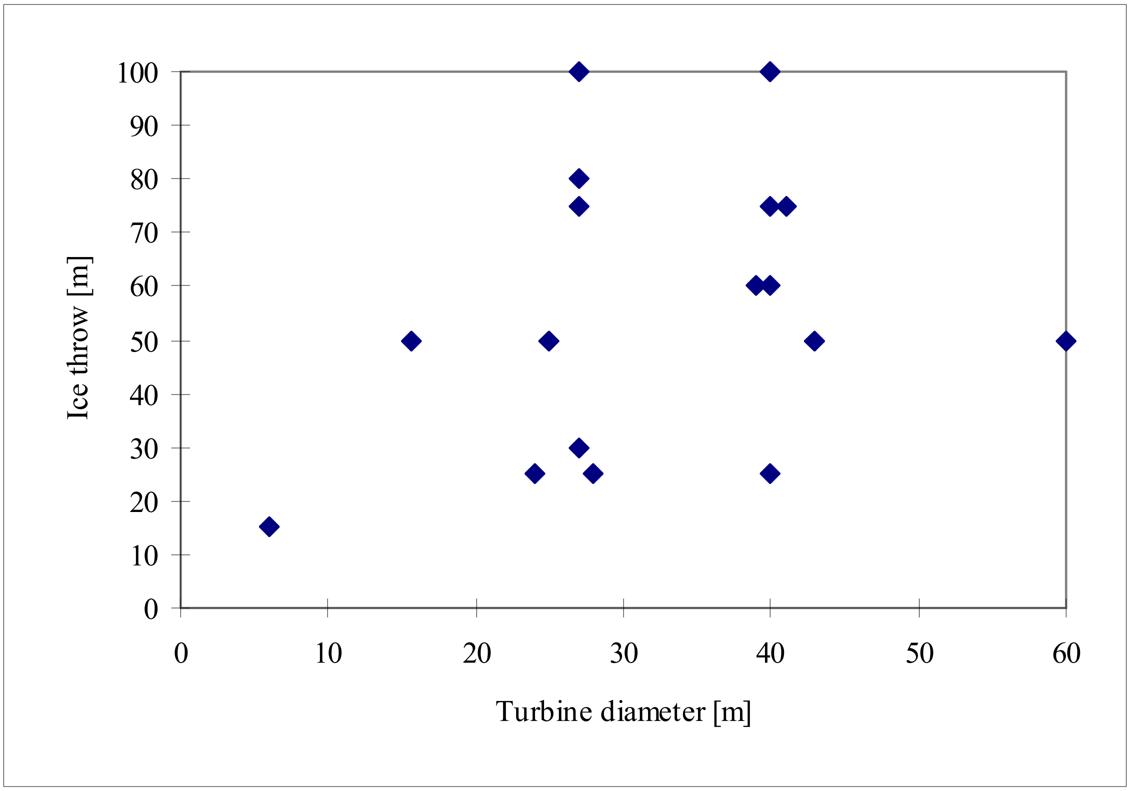

Figure 3 Recorded ice throw data [from 5]

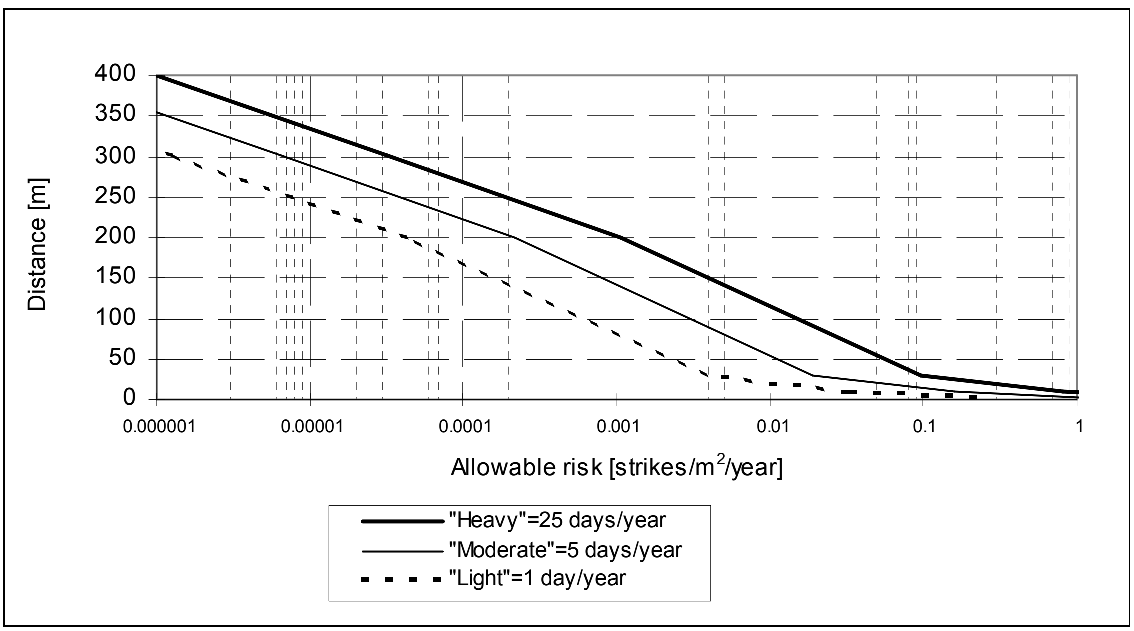

Figure 4 Safety distance for different icing levels [from 2]